TECTONIC RESURFACING ON GANYMEDE AND ITS ROLE IN THE FORMATION OF GROOVED TERRAIN

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Introduction and Background: Voyager data [1] revealed details of the surface of Ganymede, known previously to consist largely of water ice [2], and showed a surface comprised of approximately one-half relatively low-albedo terrain consisting of heavily cratered and furrowed regions, and one-half younger relatively brighter terrain, characterized by distinctive lanes of linear grooves and complex groove polygons. This information permitted the subsequent geological, characterization of Ganymede [3]. On the basis of Voyager data, bright terrain consists of smooth plains and linear grooves (troughs) averaging about 4 km in width arranged in a global network [3, 4]. The bright terrain in which the grooves formed is thought to have been emplaced by cryovolcanic resurfacing of dark terrain, often to a depth of several kilometers [4-6]. The occurrence of patches of smooth, ungrooved bright material and the confinement of bright material by apparent fault scarps are strong evidence that this material was emplaced in fluid form [1,4,5], and in some cases, light material appears to have been emplaced as a very thin mantle on older, rough topography [7, 8], suggestive of explosive ice-volcanism predicted to accompany eruption of aqueous melts [9]. These analyses were the basis for Galileo mission planning and the selection of specific targets to assess and test hypotheses for the origin of the array of features and processes revealed by Voyager. Here we report on data from Uruk Sulcus [10] and several other bright terrain target regions viewed at high resolution on Galileo orbits G1 and G2, and describe evidence for the process of tectonic resurfacing and its significance in the emplacement of the bright terrain as revealed in these data.

Observations and Analysis: The region targeted in Uruk Sulcus displays bright grooved terrain consisting of typical complex polygons of interspersed smooth and grooved material adjacent to segmented dark terrain of Galileo Regio [11]. Although regional evidence has been cited for the volcanic flooding of rift zones to produce the broad lanes of bright terrain and locally resurface polygons [8, 11], we find no direct evidence [10] for cryovolcanic activity (e.g., smooth unmodified plains, lobate flow fronts, flooded and embayed terrain, pyroclastic mantling, etc.) in these images. Instead, sequential and pervasive tectonic deformation dominates the surfaces of all units in the Uruk Sulcus analysis area. The characteristics of the latest events reveal evidence for tectonic deformation that destroys preexisting topography, craters, and geologic units to such an extent that the deformation qualifies as a major resurfacing process in the evolution of bright terrain. For example, a polygon of grooved terrain with internal structures generally trending N-S (Fig. 1 at A; see also URL http://www.pdsimage.jpl.nasa.gov/cgibin/PIAGenCatalogPage.pl?PIA00277) appears relatively smoother at both Voyager and Galileo resolution than the throughgoing groove lane (B) and is similar to the terrain often thought to have represented relatively recent cryovolcanic resurfacing of grooved polygons [8, 11, 12]. We find no evidence for geologically recent resurfacing and find positive evidence that this terrain is actually older than the adjacent groove lane. The smoother region has a higher density of impact craters indicating an older age, and the southern margin is cut tectonically by ridges and troughs of the groove lane; parallel fractures in the polygon become troughs and ridges over a distance of several kilometers (C). We interpret this to mean that terrain at B is forming tectonically at the expense of terrain at A, and that the narrow zone of faults at C shows the transition zone of older terrain being destroyed tectonically. In this case, the faulting is so intense that the original texture of terrain at A is completely destroyed and is unrecognizable in the new unit. The rotational tilt-block faulting typical of the unit at B (Pappalardo et al., this volume) thus may be an important mechanism for tectonic resurfacing. Further evidence for this interpretation is seen just to the northwest in Fig. 1. Here a second polygon (D) is rougher-textured than the adjacent one (A); its ridges are more prominent and trend in a different direction. In this case, the distinctive eastern bounding fault of terrain B marks the location of a wider transition zone then to the south. Where ridges are most prominent in the polygon at D, there is most evidence for relict structures of the same trend extending out into the unit at B, but cut by the structures of unit B. Although some complications may exist in relation to the shear zone (E) just to the north, we interpret the observed relationships to mean that where preexisting structure is relatively subdued, tectonic resurfacing is very thorough (A to B transition), but where preexisting structure is more prominent, some relict trends can be observed (D to B transition). In a second example, (Fig. 2, see also URL http://www-pdsimage.jpl.nasa.gov/cgibin/PIAGenCatalogPage.pl?PIA00280) the polygon at A appears smoother at Voyager resolution than the throughgoing groove lane (B) and was also a candidate for material that had been cryovolcanically resurfaced and was relatively young. Galileo images show however that terrain at A is more heavily cratered and that structures associated with the groove lane (B) cross-cut the structures of the polygon at A. In detail, the transition zone is a few km wide and in this zone one can observe cross-cutting groove lane faults progressively destroying the linear texture of the polygon in a manner comparable to the relationships seen in Fig. 1 (A to B). In several cases, the faults at the edge of A can be traced laterally into ridges and troughs in B. In addition, one of the most striking pieces of evidence for the tectonic destruction of pre-existing terrain is the truncation of the 8 km diameter crater (C); here, one-half of the crater has been virtually completely obliterated by rotational domino-style faulting and the rollover (Pappalardo et al., this volume) associated with groove lane formation. The only evidence for the presence of the crater rim in the groove lane is the presence of rougher, more fragmented ridge topography. We interpret these relationships to indicate that the groove lane is younger and forming by tectonic destruction and resurfacing of older grooved polygons. Although we cannot conclusively rule out the hypothesis that the groove lane involved graben formation, followed by cryovolcanic resurfacing of the downdropped block, followed by tectonic modification of the downdropped and resurfaced block [12, 8], we see no direct evidence for this sequence and find that the tectonic resurfacing hypothesis does not require an intermediate stage of cryovolcanic resurfacing. We see similar evidence for tectonic resurfacing by throughgoing groove lanes in Nippur Sulcus (Head et al., this volume).

Preliminary Conclusions and Implications for Resurfacing Models: In summary, evidence for tectonic resurfacing and implications include: 1) transitions can be seen near margins (cut craters, segmented linear trends, transitional fractures, etc.) and are evidence that the resurfacing is dominantly tectonic; 2) in this process, younger units are formed by tectonic dismemberment of older units and trends; 3) recognition of rotational domino style faulting as a process that can destroy older terrain very efficiently (Pappalardo et al., this volume); 4) associated loss of impact craters resurfaces older units from an age point of view; 5) no specific evidence for cryovolcanic resurfacing (vents, lobate flows, extensive smooth plains, etc.), although earlier units/bright terrain as a whole may have been emplaced cryovolcanically. Several models have been proposed for the formation and evolution of bright grooved terrain seen in Voyager data; on the basis of information extractable from images at Voyager resolution, it was agreed by a variety of researchers [12, 8, 7] that the dark terrain was broken into successively smaller blocks by progressive fracturing, and that the blocks were cryovolcanically resurfaced and then deformed internally. Basic disagreement exists, however, concerning the sequence of events during bright terrain formation. Golombek and Allison [12] suggested that the breakup preceded a later stage of resurfacing, which somehow preserved the older, throughgoing grooves outlining the lithospheric blocks. Murchie et al. [8] proposed a more complex history in which resurfacing and groove deformation were interspersed, and the oldest throughgoing grooves were later reactivated and occupied by younger tectonic features. The main reason for this divergence in views was that the critical morphologic details key to determining stratigraphic relations were below the resolution of the Voyager images over most of the satellite. On the basis of our observations in Galileo imaging data, we conclude that these models can be modified by the following observations: 1) many of the small polygons thought to be relatively young and cryovolcanically resurfaced are in fact older and that they may represent a population of polygons that formed earlier as a part of more extensive terrain and then were later tectonically dismembered by throughgoing groove lane formation, and 2) tectonic resurfacing may provide a viable alternative to cryovolcanic resurfacing in the evolution of the grooved terrain, particularly in the later stages of its tectonic evolution. Subsequent imaging targets during the Galileo mission are designed to provide data on other critical sites relative to the breakup of dark terrain and the emplacement of bright terrain.

References: 1. B. Smith et al.(1979)*Science*, *204*, 951, *Science*, *206*, 927; 2. C. Pilcher et al. (1972) *Science, 178*, 1087; 3. E. Shoemaker et al. (1982) *The Satellites of Jupiter*, 435; 4. B. Lucchitta (1980) *Icarus*, *44*, 481; 5. E. Parmentier et al. (1982) *Nature*, *395*, 290; 6. P. Schenk and W. McKinnon (1985) *JGR, 90*, C775; 7. P. Helfenstein (1986) *LPSC XVII*, 333; 8. S. Murchie et al. (1986) *JGR, 91*, E222; 9. L. Wilson and J. Head (1984) *LPSC XV*, 924; 10. M. Belton et al. (1996) *Science, 274*, 377; 11. J. Guest et al. (1988) *USGS Misc. Inv. Ser.*, Map I-2289; 12. M. Golombek and M. Allison (1981) *GRL 8*, 1139.

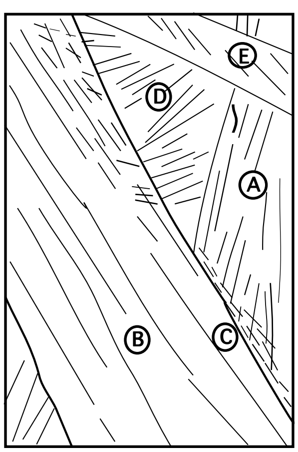

Figure 1. Portion of Uruk Sulcus G1 target: Width of image is about 46 km. North toward top.

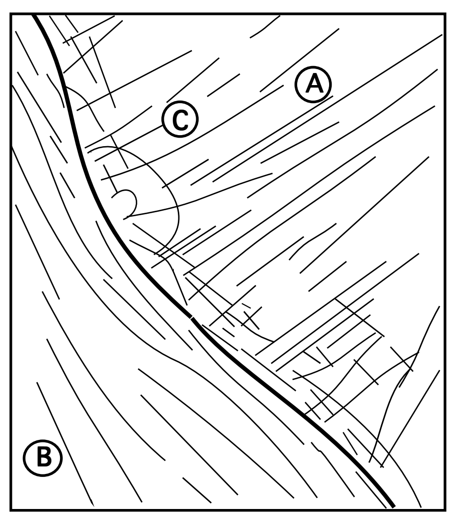

Figure 2. Portion of Uruk Sulcus G1 target: Width of image is about 31 km. North toward top.